ERDC/CERL TR-05-23

Construction Engineering Research Laboratory

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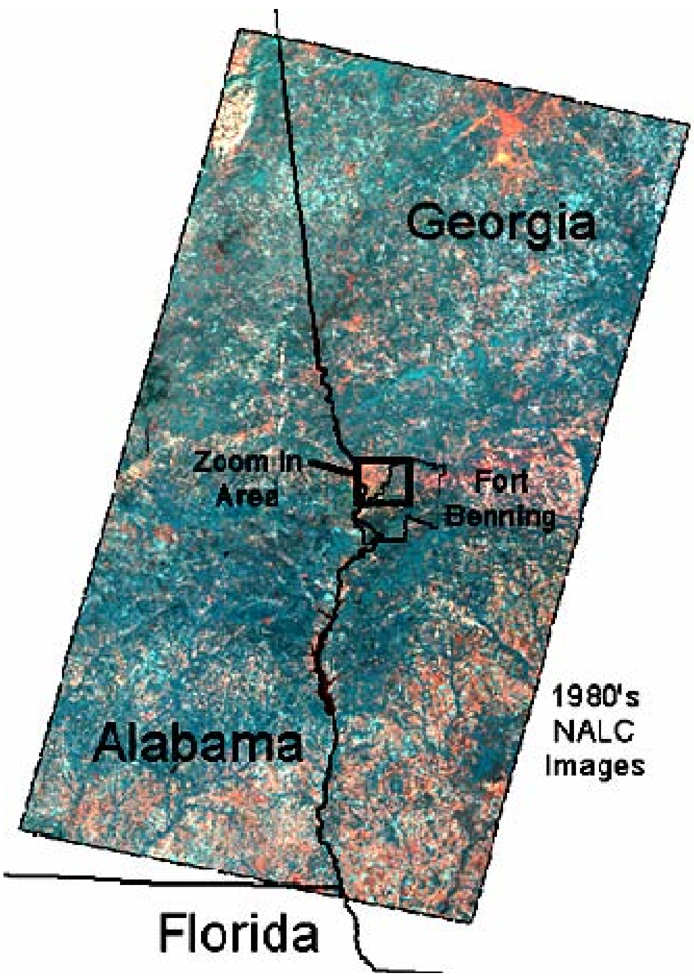
Use of the Corridor Tool in Support of Threatened and Endangered Species Habitat Fragmentation

Input Procedure and Initial Results

Robert C. Lozar, William Hargrove, and Forrest Hoffman

September 2005



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Use of the Corridor Tool in Support of Threatened and Endangered Species Habitat Fragmentation: Input Procedure and Initial Results

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Final Report

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Under Work Unit No. CNN-T602FF, “Quantify Effects of Fragmentation and Approaches to Mitigate”

ABSTRACT: Researchers at the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL, determined that a "Corridor Tool" developed by the Oak Ridge National Laboratory (ORNL) could serve to further focus ongoing "habitat" research on habitat fragmentation at the landscape scale. This work tested the ORNL Corridor Tool on data related to Red-cockaded Woodpecker habitat fragmentation in the southeastern United States using widely available data to run the Corridor Tool, and to develop a general corridor analysis.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

*_Système International d'Unités_ ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), under Project 4A162720A896, "Environmental Quality Technology"; Work Unit CNN-T602FF, "Quantify Effects of Fragmentation and Approaches To Mitigate." The technical monitor was Dr. William Severinghaus, Technical Director, and Military Lands Management Division.

The Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL), performed the work. The CERL Principal Investigator was Robert C. Lozar. The technical editor was William J. Wolfe, Information Technology Laboratory. Alan B. Anderson is Chief, CEERD-CN-N, and John T. Bandy is Chief, CEERD-CN. The associated Technical Director is Dr. William D. Severinghaus, CEERD-CV-T. The Acting Director of CERL is Dr. Ilker K. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Oak Ridge National Laboratory (ORNL) has developed an electronic (software) "Corridor Tool" to determine potential wildlife corridors between patches of habitat (Hargrove et al. 2004b). Researchers at the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL, determined that this tool could complement on-going CERL research into threatened and endangered species (TES) habitat to further focus "habitat" research on the issue of habitat fragmentation at the landscape scale. Consequently, CERL partnered with ORNL to test the ORNL Corridor Tool on data related to Red-cockaded Woodpecker (RCW, *Picoides borealis*) habitat fragmentation in the southeastern United States. CERL's responsibility in this effort was to generate the background data to characterize the RCW inputs for the Corridor Tool while ORNL was to format these inputs and run the Corridor Tool.

Although there is abundant data on the RCW on the military installations, data pertaining to other locations is very limited and of uneven quality. Published data (USFWS 2003, Kulhavy et al. 1995) does provide tables and disjointed distributions with a domain based on state boundaries, yet baseline information as simple as a single digital, spatially explicit map of known breeding colonies does not exist (personnel [email] communication with R. Costa, 23 September 2004). To cover large areas of the Southeast at the landscape scale, researchers used widely available data (remotely sensed imagery and its derived products, specifically from data derived from the National Land Cover Data [NLCD]) to run the Corridor Tool, and to develop a general corridor analysis.

Objective

The overall objective of this project was to identify critical landscape scale corridors for the militarily important TES Red-cockaded Woodpecker in the regions surrounding installations within the southeastern United States. The specific objective of this work was to generate TES RCW input to test the ORNL Corridor Tool at the landscape scale.

Approach

The procedure used was:

1. Current, known locations of the RCW at Fort Benning GA, were correlated with NLCD land uses.
2. Similar locations within the study region were found.
3. Small areas below a threshold in the data were removed to decrease the CPU requirements on the Corridor Tool.
4. The Corridor Tool was run using the generated input.
5. Results were gathered, analyzed, and evaluated.

Scope

This work was intended to test the Corridor tool's capabilities at predicting TES fragmentation characteristics as a landscape scale. As such, the following limitations should be recognized:

- The Corridor Tool is in a state of development. This work is to be considered an initial test.
- Because fragmentation evaluations are carried out at the landscape scale,this project is limited in its base data source to the National Land Use Data (NLCD) set. It is recognized that;
  - This data inadequately represents all the data necessary to characterize TES habitat and corridor characteristics.
  - This is the only landscape scale data set available to support the analysis.
- Although characteristics of the TES, Red Cockaded Woodpecker are used, this modeling study does not yet fully represent these characteristics.

While input data, TES parameters, and the model itself should be considered a realistic example of how the Corridor Tool can be applied to TES fragmentation issues, they do not represent a final conclusion about critical RCW corridors near the Columbus, GA region.

This work focuses on the four-state region of the Sandhills ecosystem, and is limited to the NALC Path-Row locations 19-37 and 19-38 and on the TES RCW. Although it is intended to be applicable to other regions and other TES, this work was initiated primarily to test the ORNL Corridor Tool and generate inputs and results specific to that package.

This work is not intended to develop another RCW habitat model, potential habitat map, or a population dynamic simulation model; it is meant to focus on the issues of fragmentation and on the identification of critical lands outside of military installa-

tions that might not be habitat, but that are critical to the issues of species genetic interaction. The methodology was focused specifically on meeting the requirements of the Corridor Tool.

Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 Setting the Stage for the Corridor Research Initiative

To carry out its obligations and responsibilities regarding both national defense and threatened and endangered species, the Army must understand and accommodate key areas relating to threatened and endangered species, and cooperate and interact with other Federal, state, and local managers, and with the public. Specific areas that must be addressed include the key habitat fragmentation corridors on and off Army installations and need to be able to predict habitat trends.

By delineating a regional spatial distribution of key habitats for TES off installations, the Department of Defense (DOD) and Army can identify key locations for habitat preservation. This objective method can help identify and act upon beneficial partnering to cost effectively limit habitat fragmentation. Army installations — either individually or as part of a regional plan—have goals to be met in terms of species recovery. If the military identifies and supports the creation of additional areas off installation as part of a "protective ownership" condition, it is hoped that the Fish and Wildlife Service (FWS) may be willing to decrease their requirement within the militarily active lands. It would be a benefit—to the military, to the TES populations themselves, to the FWS (due to greater recovery potential), and (usually) to the local communities—to have lands set aside for conservation. This project seeks to identify those areas that may present this mutually beneficial opportunity.

ORNL has developed a Corridor Tool that uses landscape scale, species-specific inputs to identify key spatially explicit characteristics of landscape and habitat fragmentation. This analytical tool can predict the location of corridors of movement between patches of habitat within any map. The algorithm works by launching virtual entities called "walkers" from each patch of habitat in the map, simulating their travel as they journey through land cover types in the intervening matrix, and finally arrive at a different habitat "island." Each walker is imbued with a set of user-specified habitat preferences that make its walking behavior resemble a particular animal species. Because the tool operates in parallel on a supercomputer, large numbers of walkers can be efficiently simulated.

The Corridor Tool uses the concepts of "source" and "sink." For each habitat patch, a relative measure of how easy it is to disperse from here to somewhere else is the

definition of how much this patch has the character of a source. How easy it is to disperse to here from somewhere else is the definition of how much this patch has the character of a sink. These relative measures are similar to those used by Pulliam (1988), but they are independent of within-patch reproduction. Source and sink importance are calculated for each patch. Manipulation of a series of contrived artificial landscapes demonstrates that the location of dispersal corridors, and relative source and sink importance among patches can be purposefully altered in expected ways. Finally, dispersal corridors are predicted among remnant habitats within three actual landscape maps. Specifically, the tool can identify critical "connectance points" in a landscape that can therefore be used to direct military resources toward the most critical areas of concern, or otherwise evaluate alternative locations for the degree of suitability to act as potential, long-term habitat recovery sectors.

The Corridor Tool has been tested on theoretical and small realistic areas. We wished to apply it to a specific region and to a specific species. The specific TES we wished to begin modeling is the Red-cockaded Woodpecker. Using the Sandhills Data Set, it was not only possible to model the fragmentation character over the study area, but also to quantify and monitor the location and quality of habitat corridors over a multi-decade time period (1970s-1990s).

Initial feasibility testing was to be done on a small rectangular area centered on Fort Benning GA using the two 1980s NLCD coverage's (path/rows 1937 and 1938). The input data required for the Corridor tool to process this smaller test area was, in several cases, identical to that required doing the entire Sandhills region. Thus, effort spent to parameterize the initial area will be directly applicable when finding corridors within the larger four-state area.

This work will begin to identify and delineate key least-fragmented habitat patches at a landscape scale level, primarily off-installation. This will help the military to work with other agencies to identify and prioritize those areas off installation most likely to preserve or decrease the level of RWC TES commitment on installation to TES habitat that conflicts with military mission activities.

For the most part, the RCW recovery plan does not currently envision connecting the separate and isolated RCW populations. Instead, this work hopes to recognize and reinforce the logic of ensuring the interaction of currently isolated populations to protect their long-term viability and genetic diversity. Also to keep this work in perspective, this initiative uses RCW as an initial example of the Tool's potential wider applicability to other species.

Tasks To Run the Corridor Tool

The process to run the Corridor Tool followed these steps:

1. *Define/agree upon test area.* This area was defined as a region around Fort Benning GA, path/rows 1937 and 1938. (Determining this parameter was a CERL responsibility.)
2. *Define input matrix needed for Corridor Tool.* For each land-use type to be used, the land use characteristics in relation to RCW must be defined. (Determining this parameter was a CERL responsibility.)
3. *Generate Patch layers.* For each of the land uses in the previous task, a spatially explicit patch layer will be generated. These patch layers will contain are consecutively numbered patches. The finding of the patches is the rate-limiting step for the size of a map that can be analyzed. Patches of less than an agreed upon minimum size were to be included in a separate layer as patches of a particular character, but not a viable habitat patch. This minimum size was to be in the many hectare range (~1 kilometer) to ensure a manageable amount of land. CERL generated the patches using the ESRI ArcView Extension Tool called "Patch Grid."
4. *Input the data to the Corridor Tool.* (This activity was an ORNL responsibility.)
5. *Run the Tool.* (This activity was an ORNL responsibility.)
6. *Evaluate the Results.* (This activity was a shared ORNL and CERL responsibility.)

Significance to the Army

Currently, the DOD is carrying a large burden of TES management within a region. To successfully carry out its TES management responsibilities, DOD must cooperate with other Federal, state, and local land managers to provide viable habitats. Otherwise, specific Army installations will become unique TES refuges. This effort is meant to begin to objectively and clearly identify areas of greatest significance for RCW habitat preservation using the most advanced research tools available.

Research Issues

This work was undertaken to address a number of research questions:

- What are the key TES habitat criteria off or on installations that can be used for modeling fragmentation?
- What are the current and future habitat locations, particularly off installation, that will support TES populations?

- What are the parameters needed to reflect changes in landscape scale fragmentation?
- What are the remote sensing and national data set products (and combinations thereof) that most closely relate to the issues of habitat fragmentation for RCW (which is one of the seven TES of high concern to military installation land managers)?
- What are the measures or indices from the fragmentation habitat models that are the most telling in relation to the seven TES of most concern

Research Limitations

A major conceptual issues that this project faces is the need to identify areas of older growth Long-leaf Pine with an open under story, which is an important concern for defining RCW habitat. Unfortunately there is no source for "age of tree" across the region. The result may consequently provide overestimate potential RCW habitat. To respond to this issue one might consider that:

1. Current younger evergreen patches (those less than 40 years old) will turn to old patches under appropriate management over time. Since this study seeks areas that can be used as trade off for habitat on installations, obtaining rights to an off-installation location for the future (more than about 5 years), current conditions are not really at issue. In fact, current conditions strongly indicate that there are almost *no* viable patches anywhere within the study area off installation. The question is not *what exists*, but *what can potentially exist*.
2. Although this initial analysis is intended to cover a large region, any parcels of interest will be located nearer an installation rather than further away; the desire it to be as inclusive as possible.
3. For this work, the issue is not only to locate feasible habitats, but also to find the choke points that would make the use of a larger adequate patch immaterial because no species mixing will occur. Therefore, the focus of this work is more on the *connectivity* than on the habitats themselves. It is important to understand that this work is aimed at determining corridors; there no intention to compete with established detailed habitat models.

3 Step-by-Step Procedure To Derive ORNL Corridor Inputs for RCW

The purpose of this chapter is to carefully describe the inter-relationship between the basic literature on the TES we are modeling and the application of geographic information system (GIS) technology to develop a sound spatial and statistical basis for the Corridor Tool inputs. To Derive ORNL Corridor Inputs for RCW:

1. Merge row path (Figure 1).

   Our initial problem is that we needed to know the potential RCW habitat over a large region, but we only had data for the portion of the region within Fort Benning boundaries. So we needed to find the characteristics of the area within Fort Benning was inhabited by RCW at that point in time. To do this we compared the RCW tree locations within Fort Benning to Fort Benning as a whole to see the relative RCW preferences. As a first step, we defined the RCW tree locations by defining a 90-meter buffer around known RCW sites on Fort Benning (Figure 2). The reason for this is, if an RCW tree location were at a cell center, then with 60-meter cells, there would be 30 meters to an edge plus one cell of 60 meters.

2. Cut out land uses that are within RCW buffer.
3. Find % of different land uses (Table 1).
4. Cut out land uses that are within Fort Benning (Figure 3).
5. Find % of different land uses (Table 1).

   RCW preferences are those where the land uses are greater than normal (normal = Cut out land uses that are within Fort Benning). Then we subtract Benning land uses from RCW Land use preferences. A positive difference is a weighted RCW preference; a negative difference is a weighted RCW dislike/avoidance (Table 1).

Group weights are put into similar classes (Table 2, columns 1-5). From these we make a new map of RCW 1980 LU preferences (Figure 4) including areas outside of installation (these preferences are ordinal, not yet weighted. i.e., Figure 4 uses the Ranking LU Value from the column labeled “IRCW Percent Difference from Benning”). Notice that there exists a high preference for Evergreen Forest and Mixed Forest (10.3 and 7.4 in the *RCW Percent Difference from Benning* column). This corresponds well with descriptions from the literature (Hooper 1980 and USFWS 1985). Further, the table also reflects the RCW disdain for Deciduous Forest (a large –5.6 percent difference from the Fort Benning average). The resulting map also shows how the urban area of Columbus GA is considered undesirable.

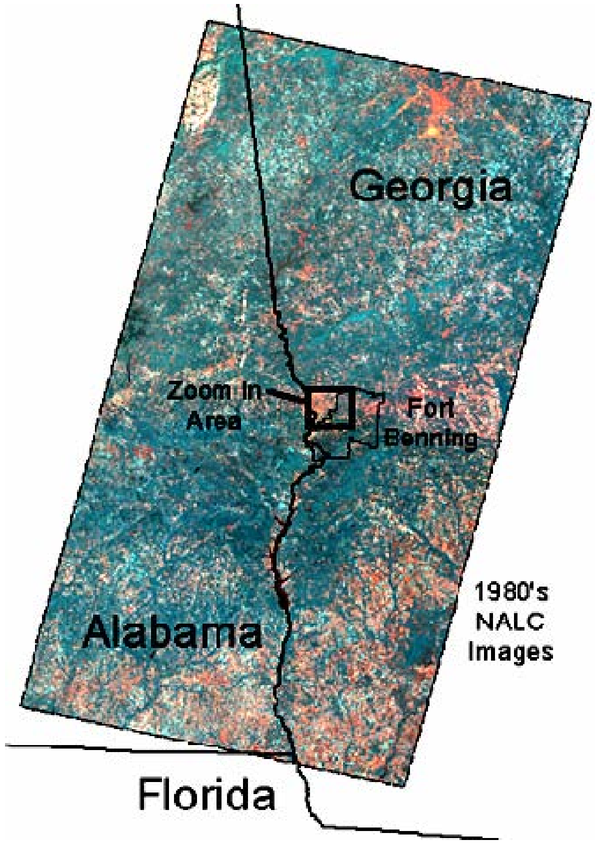

Figure 1. Test area Extent (path/rows 1937 and 1938).

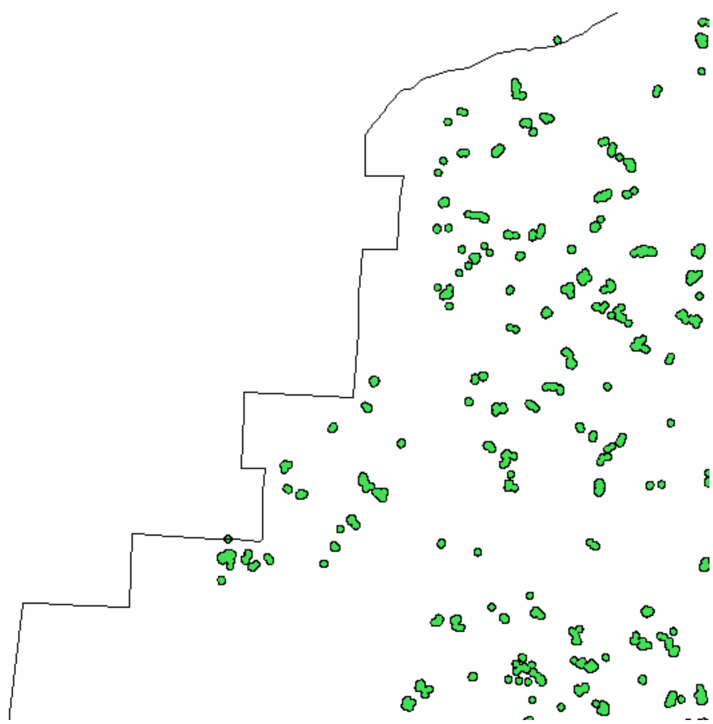

Figure 2. RCW buffers inside Fort Benning.

Table 1. RCW and land use correlations.

Land Use Category*	Pct_of_Benning	pct_of_RCW_Area	RCW_Dif_from__Benning%
Evergreen Forest	19.8452	30.1836	10.3384
Mixed Forest	30.7228	38.1491	7.4263
Pasture/Hay	0.3081	0.3648	0.0567
Bare Rock/Sand/Clay	0.0015	0	-0.0015
Emergent Herbaceous Wetlands	0.2988	0.1703	-0.1285
Row Crops	1.2636	0.9242	-0.3394
Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, Emergent Herbaceous W	1.5995	0.7661	-0.8334
Pasture, Hay, Orchards, Vineyards, Row Crops, Small Grains, Fallow, Urban-Recreational	1.5232	0.4256	-1.0976
Shrubland, Grasslands, Herbaceous Upland	1.3667	0.2432	-1.1235
Transitional	2.6024	1.058	-1.5444
Woody Wetlands	6.2234	1.7147	-4.5087
Deciduous Forest	30.1189	24.4436	-5.6753
Quarries/Strip Mines/Gravel Pits	0.0685	0	-0.0685
Commercial/Industrial/Transportation	0.6391	0.4378	-0.2013
Urban/Recreational Grasses	0.7046	0.2311	-0.4735
High Intensity Residential	0.6494	0.1824	-0.467
Low Intensity Residential	1.1364	0.3527	-0.7837
Open Water	0.9281	0.3527	-0.5754
*Appendix C to this report gives complete definitions.			

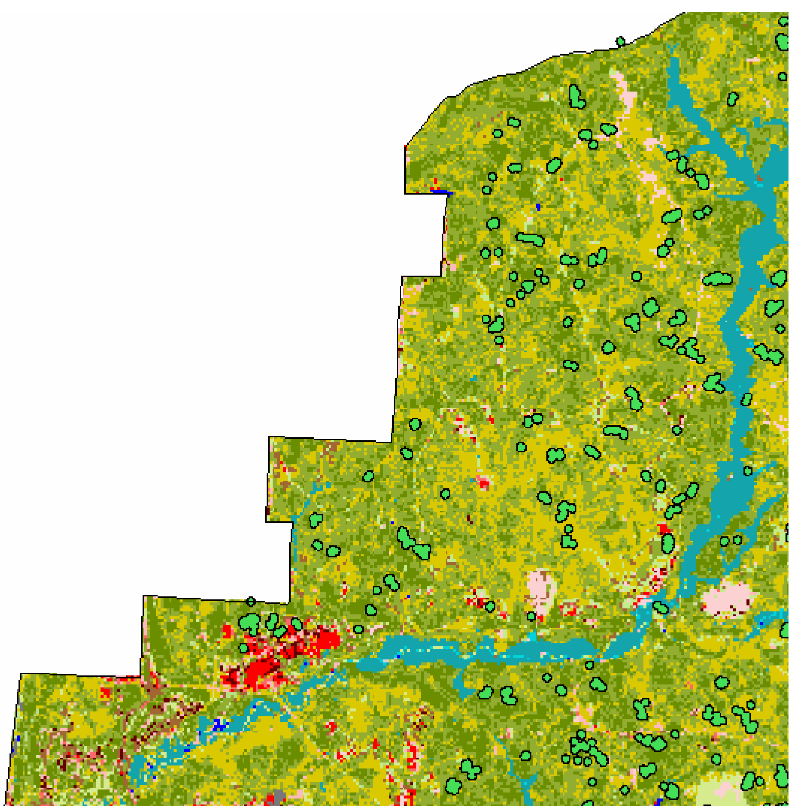

Figure 3. Land uses that are within Fort Benning.

Table 2. Land use ranking categories.

RCW_Dif_from__Benning%	Ranking LU Value	Ranking of LU	Average LU Ranking	Relative Degree of Habitat Preference	Sandhills Category	Sandhills Land Use Category
10.3384	1	Highest	10.34	1.00	42	Evergreen Forest
7.4263	2	High	7.43	0.81	43	Mixed Forest
0.0567	3	No matter	-0.63	0.29	81	Pasture/Hay
-0.0015	3	No matter	-0.63	0.29	31	Bare Rock/Sand/Clay
-0.1285	3	No matter	-0.63	0.29	92	Emergent Herbaceous Wetlands
-0.3394	3	No matter	-0.63	0.29	82	Row Crops
-0.8334	3	No matter	-0.63	0.29	40	Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, Emergent Herbaceous W
-1.0976	3	No matter	-0.63	0.29	80	Pasture, Hay, Orchards, Vineyards, Row Crops, Small Grains, Fallow, Urban-Recreational
-1.1235	3	No matter	-0.63	0.29	50	Shrubland, Grasslands, Herbaceous Upland
-1.5444	3	No matter	-0.63	0.29	33	Transitional
-4.5087	4	Avoid	-5.09	0.00	91	Woody Wetlands
-5.6753	4	Avoid	-5.09	0.00	41	Deciduous Forest
-0.0685	5	Urban-Avoid	-0.40	0.30	32	Quarries/Strip Mines/Gravel Pits
-0.2013	5	Urban-Avoid	-0.40	0.30	23	Commercial/Industrial/Transportation
-0.4735	5	Urban-Avoid	-0.40	0.30	85	Urban/Recreational Grasses
-0.467	5	Urban-Avoid	-0.40	0.30	22	High Intensity Residential
-0.7837	5	Urban-Avoid	-0.40	0.30	21	Low Intensity Residential
-0.5754	6	Water	-0.86	0.27	11	Open Water

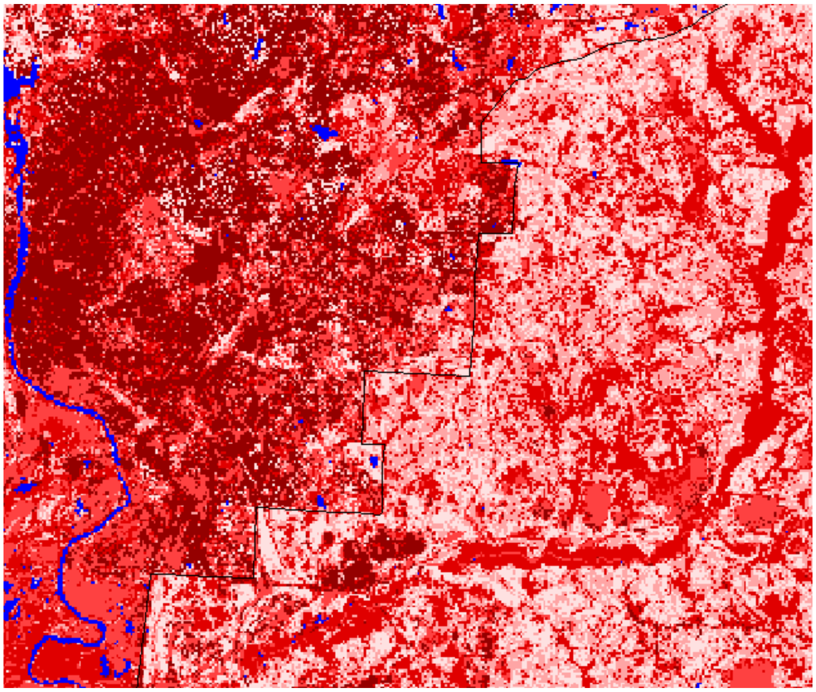

Figure 4. RCW Land Use preferences including areas outside of installation.

Next from the RCW 1980 LU preferences map, we extracted RCW 1980s preferred Locations. Figure 5 shows areas outside of the installation weighted by the Relative Degree of Habitat Preference Column. Lighter red indicates more suitable habitat. Note that weighting makes the contrast of acceptable to undesirable greater than in Figure 5.

Conner and Rudolph (1991b) say that RCW need larger patches for viable populations. From the RCW 1980s preferred locations map, find all these patches, then extract only those that are reasonably large (200 cells or 72 hectares in this research). This is the map of RCW preferred habitats (Figure 6).

Focusing on the point that the purpose of these data is to provide an input to the Corridor Tool, the literature (Walters 1989) says RCW dispersal distance averages 4km, so RCW do not wander very far from their home colonies. If the preferred large habitat patches outside the installation are the potential home colonies, then we need to generate 4km buffers from these preferred habitats (Figure 7) and decrease migration likelihood based on buffers with 4km distances.

Use the ArcView Extension Grid Patch to Combine RCW 1980s LU Preferences (six categories) with Migration Buffers (four categories) from Potential Best Habitat Patches. This becomes RCW LU Preferences Combined with Migration Buffers, 24 categories result (Figure 8) (category 7 is best = RCW home patch, category 6 is almost as good).

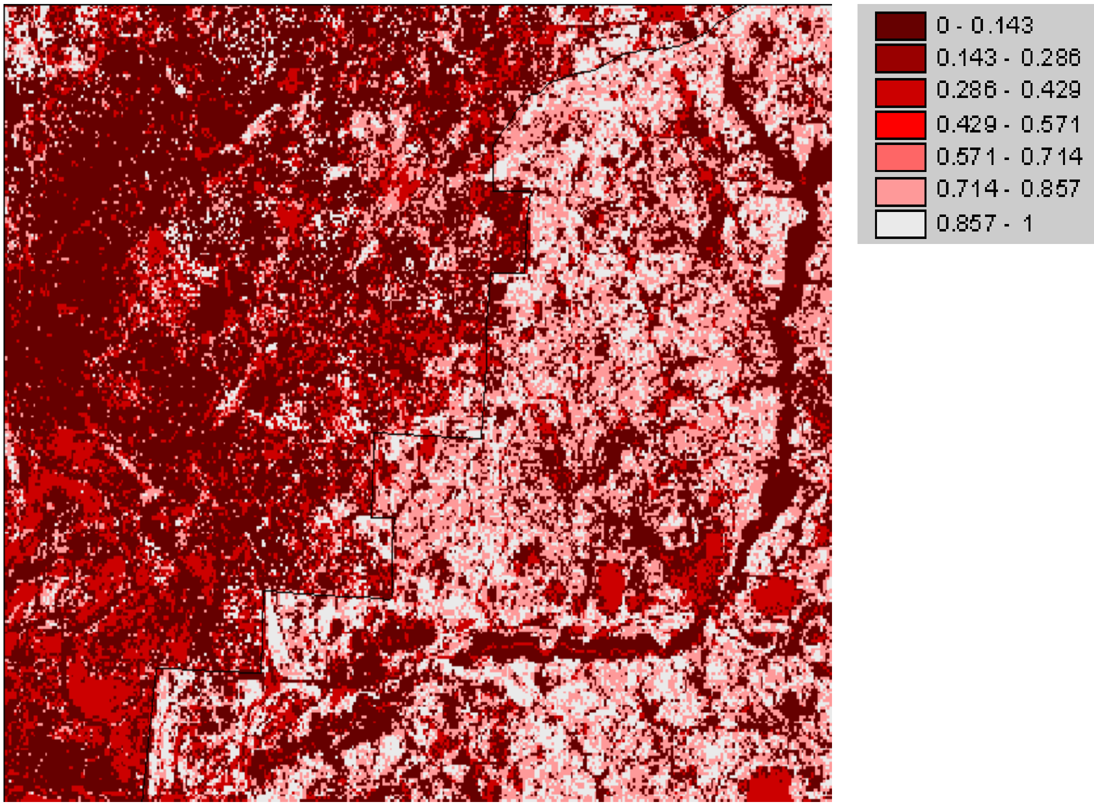

Figure 5. Coloration now weighted by the relative degree of habitat preference.

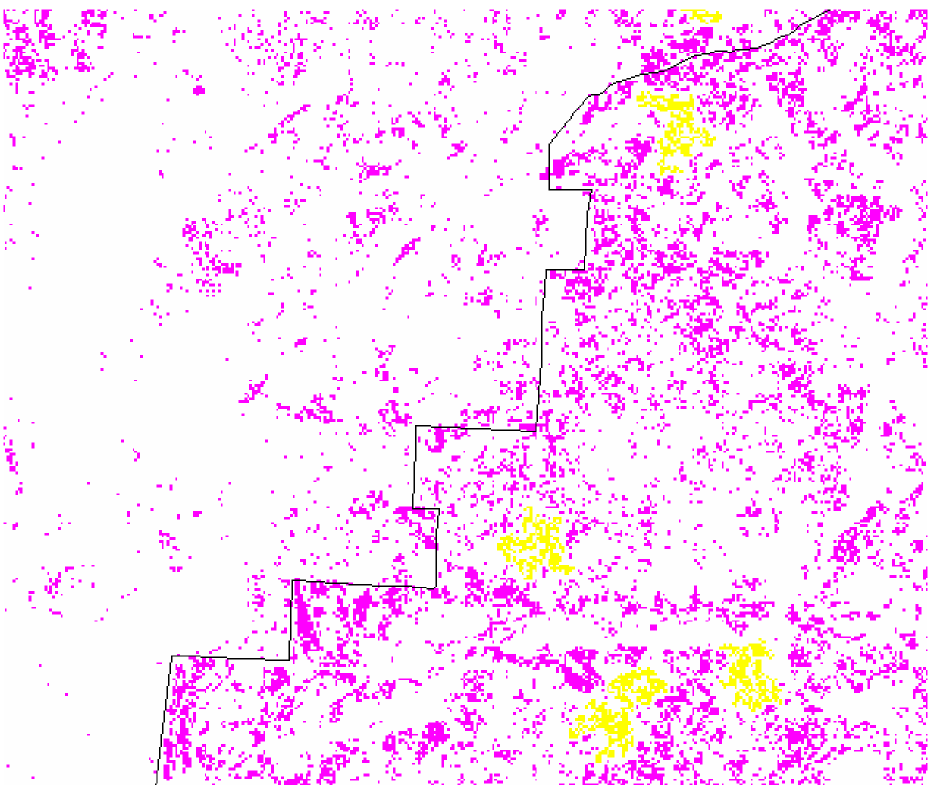

Figure 6. RCW Good locations are shown in magenta, good locations that are also large patches are in yellow.

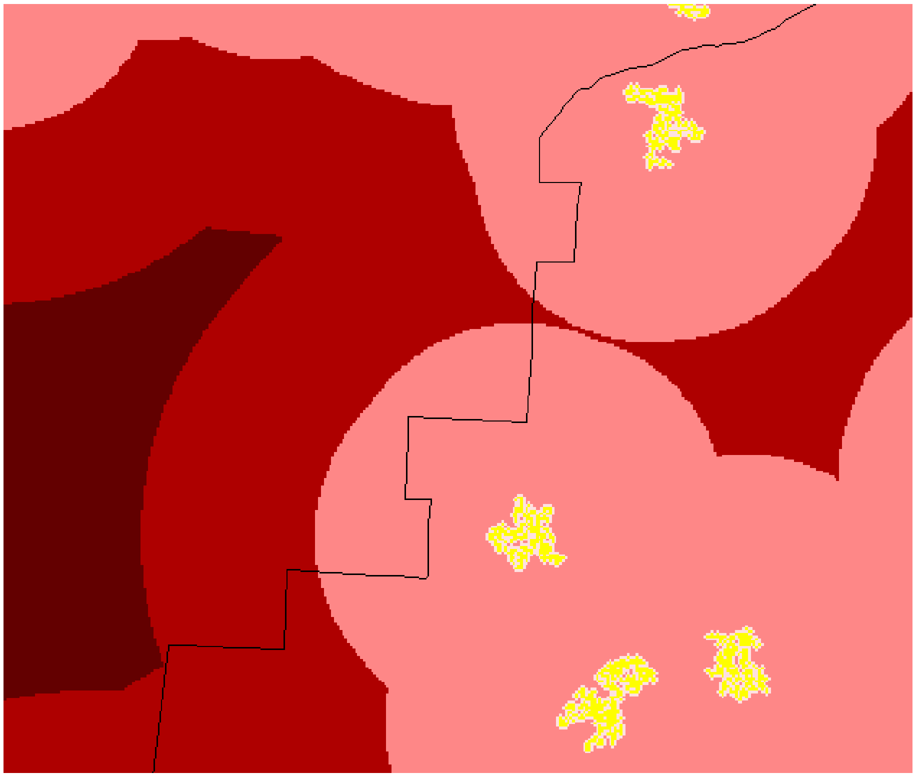

Figure 7. 4km buffers from preferred RCW habitats (yellow).

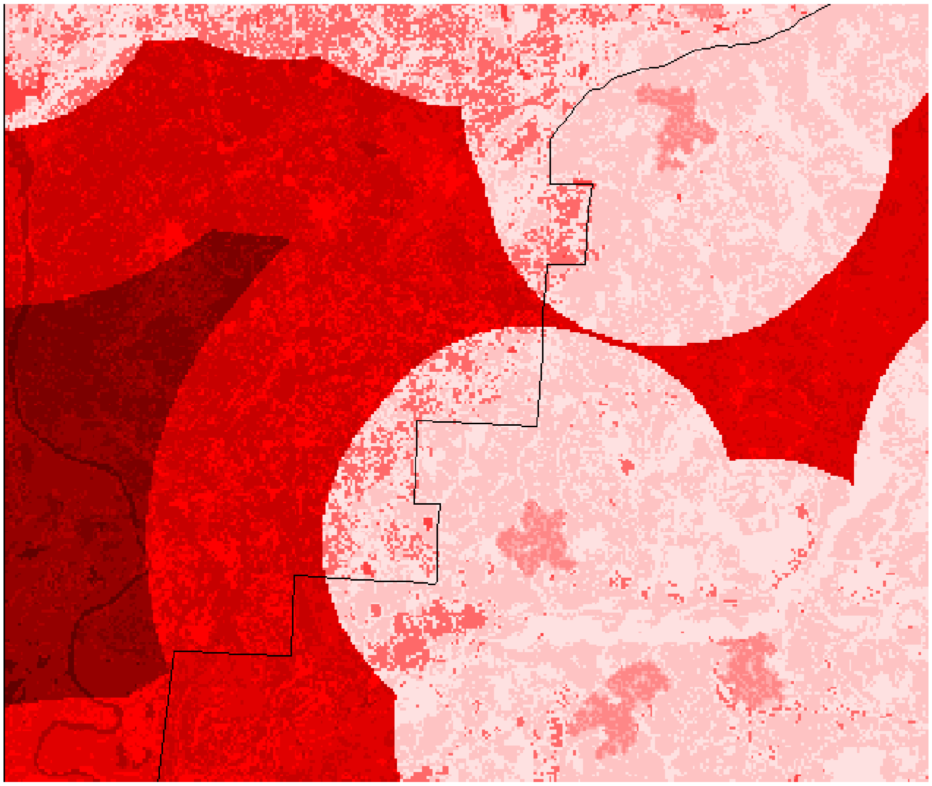

Figure 8. LandUseHabitat map: RCW LU preferences combined with migration buffers, 24 categories, no weighting.

As part of the input to the Corridor Tool, it is necessary to develop a matrix relating the 24 categories to characteristics of the studied animal (here RCW) to several major concerns:

- *Relative Degree of Habitat Preference*: Based on the LandUseHabitat map categories (i.e., those used in Figure 8). The LandUseHabitat map shows the different types of categories. The values here show the particular species preferences. This is the Relative Degree of Habitat Preference column in Table 2.
- *RCW Energy Cost to Transit Foraging*: The energy expended by the RCW to traverse a cell of each type of habitat. It is a cost of travel.
- *Mortality for Transit*: The likelihood of mortality (other than starvation) in each type of habitat.

Appendix B includes the complete weights and reasoning. The matrix was developed by first assigning the *Relative Degree of Habitat Preference* column in Table 2 to the same column in the Matrix where the LandUseHabitat category was the least distance buffer. These values are based directly on the calculated data as presented in *Relative Degree of Habitat Preference* column in Table 2. As the distance increased, the weights would decrease, depending on the concern at hand and for the reason indicated in the matrix. The values for the *RCW Energy Cost To Transit Foraging* column are determined relative to the *Relative Degree of Habitat Preference* column. We know that, in most cases, Mortality *For Transit* is almost vanishingly low for a 60-meter cell. Mostly to test the corridor model we assigned values to this column. The intent is to do sensitivity testing with additional computer runs to see how much difference this really makes.

When the values from Figure 8 are weighted by the values in the Appendix B matrix from the column entitled, *Relative Degree of Habitat Preference*, Figure 9 results, where the lighter red indicates better RCW suitability. Notice that the existing tree colonies (yellow) fit well into the better areas. Also note that the distance buffers have decreased the quality in areas away from large patches (compared with Figure 5), but have made little difference in areas near large patches.

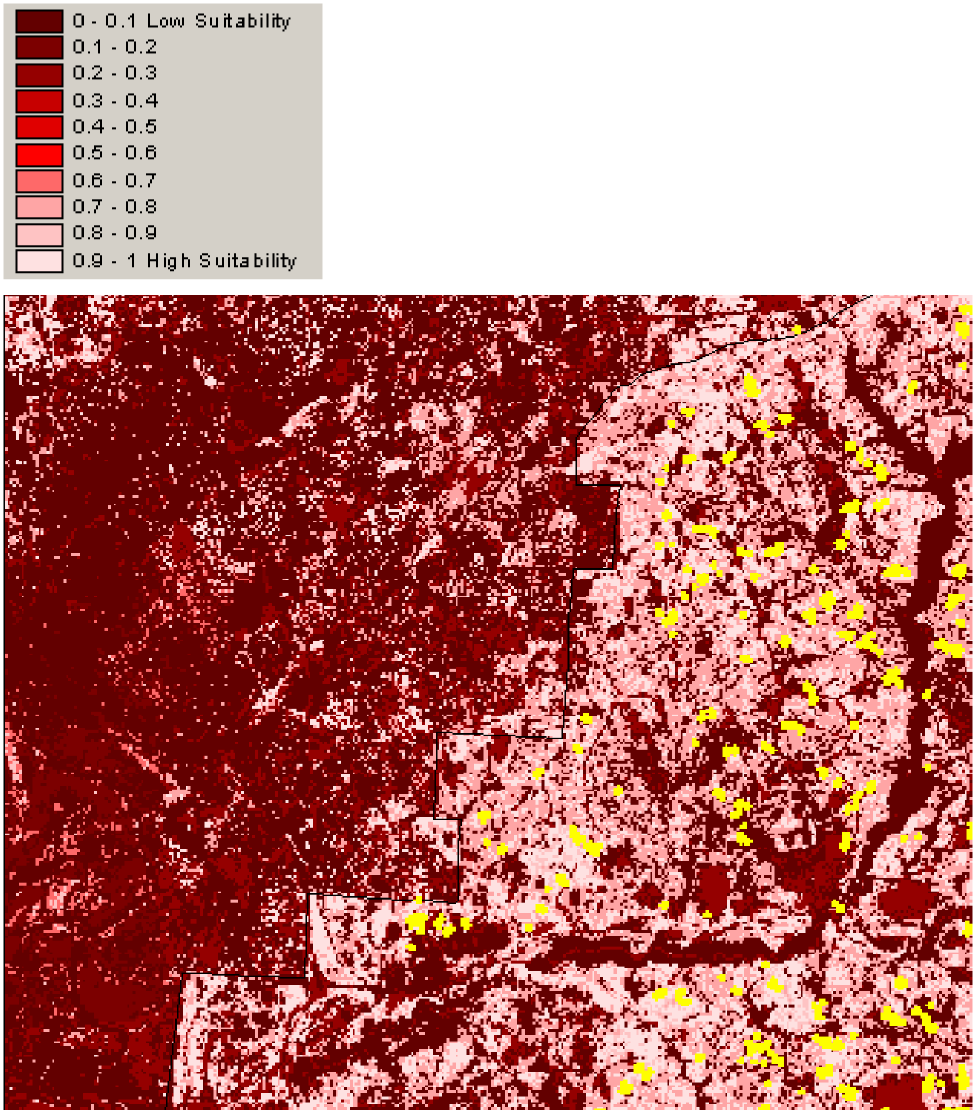

Figure 9. LandUseHabitat map weighted by the values in the matrix in Appendix B, column entitled, *Relative Degree of Habitat Preference*. Lighter Red indicates better RCW suitability. Existing tree colonies are shown in yellow.

There are *no* limits within the Corridor Tool, only the amount of memory in the machine. It is easy to recode the patches so that those smaller than the minimum area are unacceptable. By doing this, the model will better reflect the real problem, which is the finding of the patches. Since the land cover maps are derived from remote sensing, they have a lot of “speckles.” One- and two-cell patches of habitat can cause the Corridor Tool processing time to skyrocket, since corridors would have to be simulated among all of these very small patches. To avoid this, we set a minimum usable area for patches (in this case nine cells, which—if distributed as a square—would be a patch 180 meters on an edge, or 3.24 hectares). This value was chosen because it is below any critical patch size found in the literature (cf. Appendix A). This means that, at 3.24 hectares, we were guaranteeing that all critical in-

formation was preserved while we eliminated small areas below a threshold in the data. We reclassified all patches smaller than this minimum to another category, and then found corridors only among patches of the new category of patches of larger size. We used Leica Geosystems' *ERDAS Imagine*® to smooth the image out by applying the following steps:

- Use a 5x5 cell majority **Neighborhood** function to smooth
- **Clump** these areas into different patches (eight-sided) to define individual patches
- **Eliminate** remaining patches that are less than nine cells in size
- **Clump** these to get the patches numbered consecutively (using the eight-side option) and then **Export** the *img* format file to *grid* format (Figure 10).

As a final step in the development of the LandUseHabitat Map, we need to distinguish between home patches that are adequate in size for a viable population (200 cells) and those that are not. To accomplish this, the home range grid patch category 7 layer was analyzed. Category 7 was extracted separately and the *ERDAS Imagine Clump* routine was run on it. All patches of category 7 greater than or equal to 200 cell counts were identified and saved as a separated layer (Figure 11). The cell values were changed from the old patch number to category 25. Using the ArcView *GRID PIG TOOLS* extension, the two grids were merged so that the new category 25 was integrated into the LandUseHabitat Map (Figures 12 and 13).

Now as input to the Corridor Tool, we generated patch layers. For each of the land uses in the previous step, a spatially explicit patch layer was generated (cf. Figure 14). These patch layers contain patches that are consecutively numbered. To do this, in ArcView:

Select each category and save it to a layer with only that category in it.

In Imagine, for each layer:

1. **Clump** these areas into different patches (eight-sided) to get unique numbers for each patch
2. Go to **RASTER Attributes**, make a new column called numb. Populate the column by the command "set formula: row + 0, move numb to first column"
3. **Export** Image as GRID (cf. Figure 14).

To deliver the data to a Corridor Tool format, they were translated to an ASCII Grid file by using the ArcView:

Export grid to ASCII into ASCII folder

These ASCII files (LandUseHabitat map and the 25 separate numbered patch maps) were transferred to ORNL via ftp.

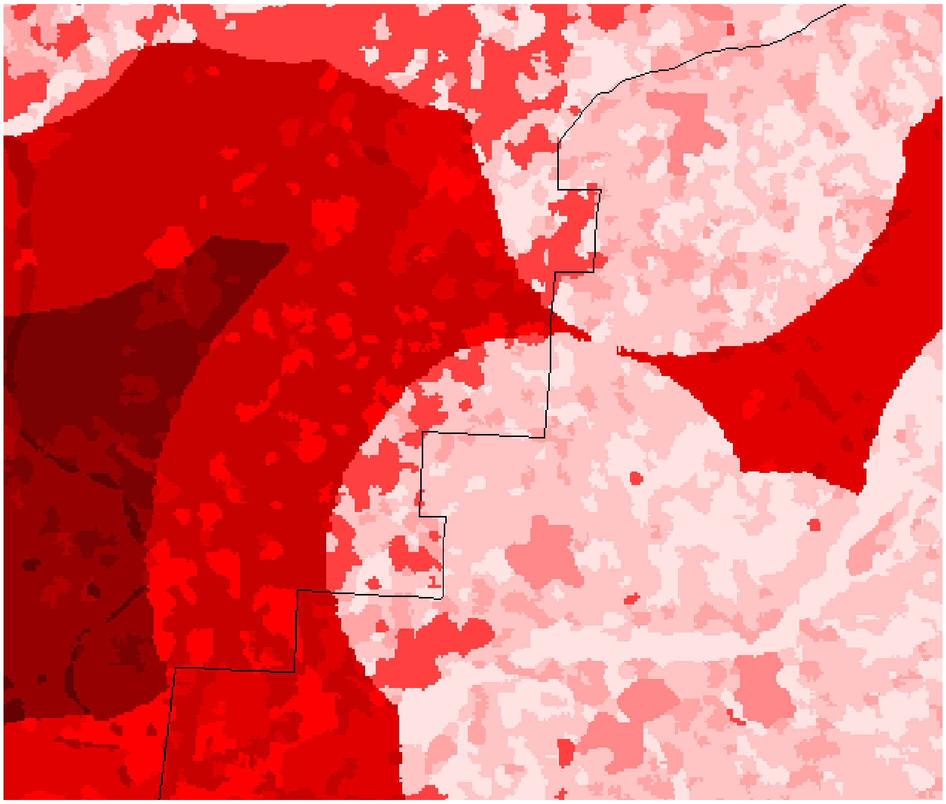

Figure 10. Smoothed LandUseHabitat Map (cf. Fig. 8); the same patterns exist, but with much less clutter.

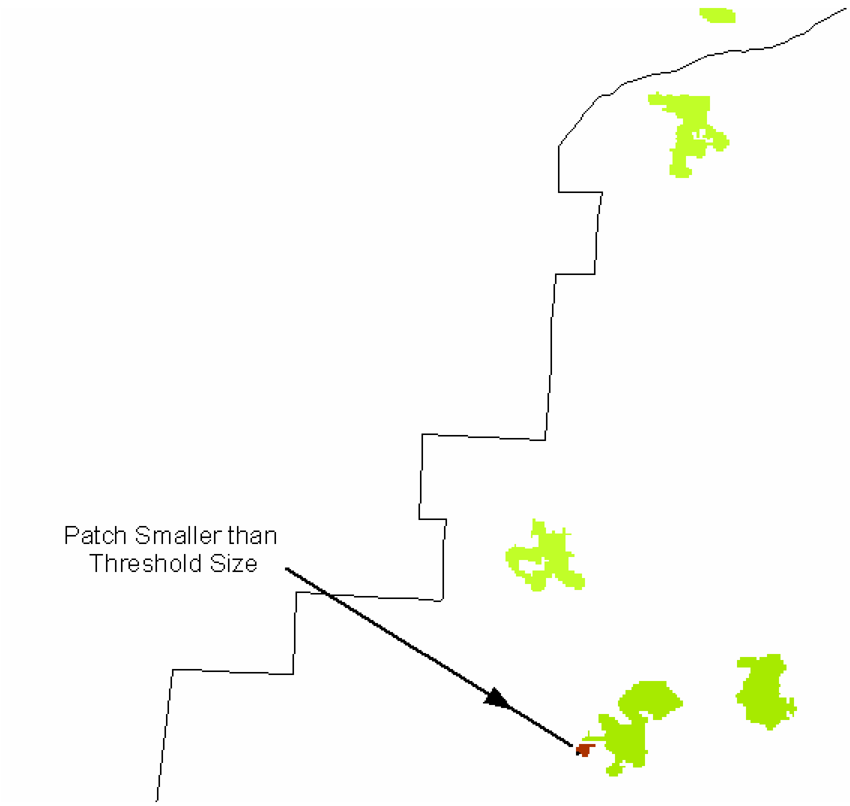

Figure 11. Patches of category 7; one in this area is less than 200 cells in size.

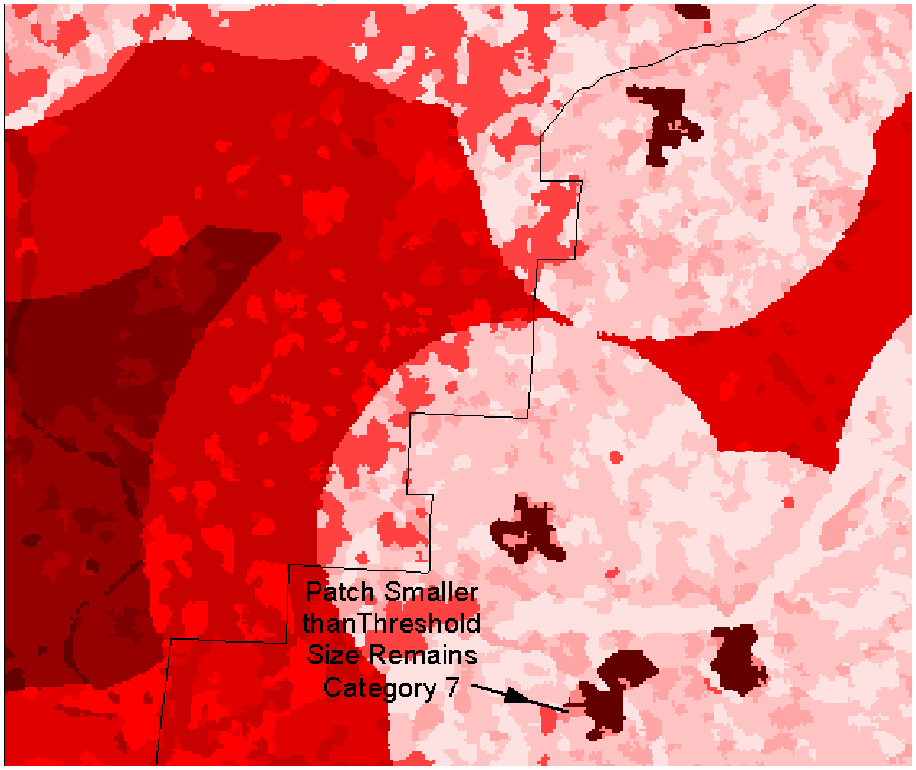

Figure 12. LandUseHabitat with 25 categories (i.e., Potential Habitats for the Corridor Tool distinguished from little islands of good habitat).

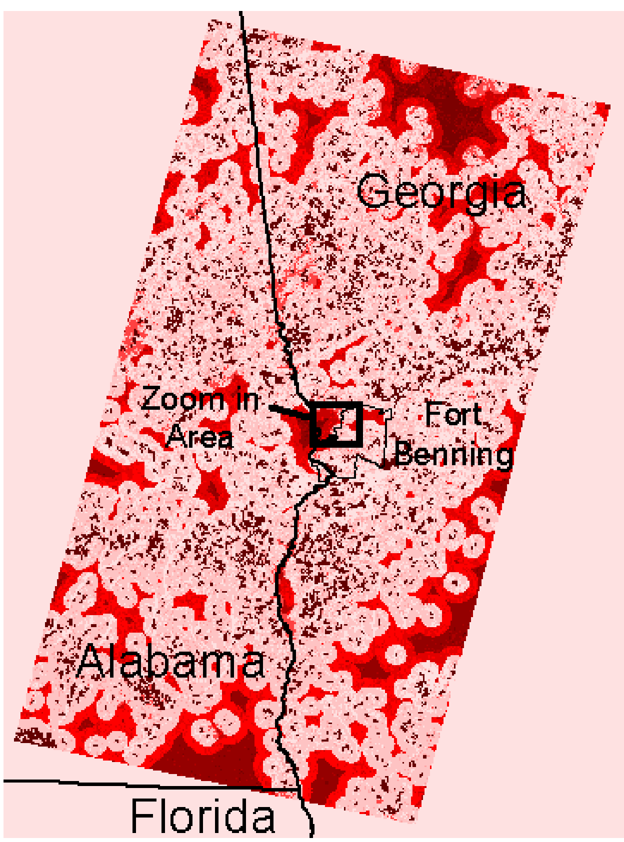

Figure 13. Same analysis over entire area.

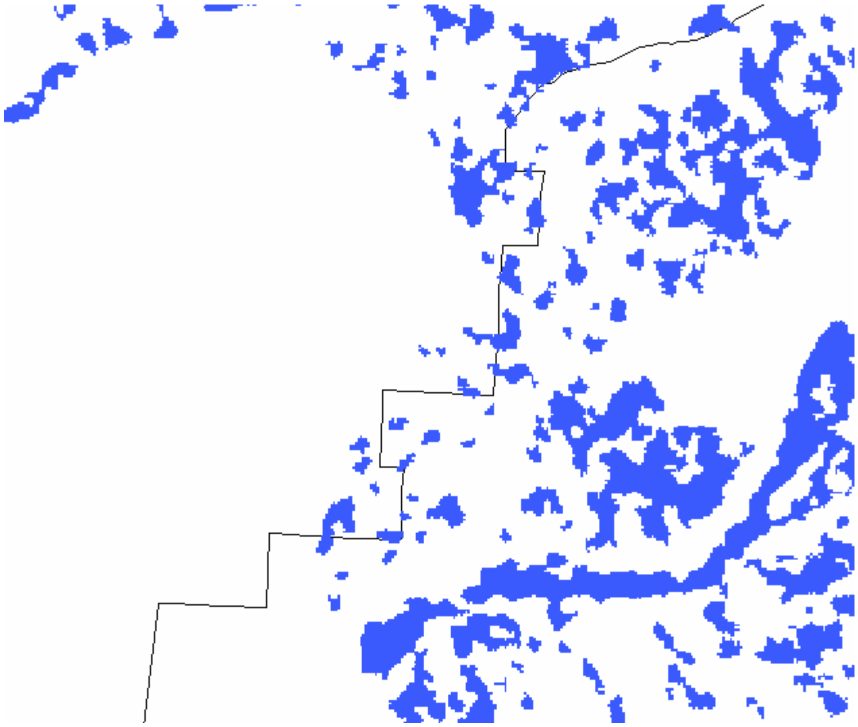

Figure 14. Layer of only Category 1.

4 The Corridor Tool and RCW Results

Rules of the Tool

Habitat fragmentation is just the inverse of habitat connectivity. For Threatened and Endangered species, the goal is to improve connectivity and strengthen corridors while for invasive species, the goal might be to disrupt connectivity and sever corridors. It has been suggested that a related application is to project the route or spread character of future invasions.

In the Corridor Detection Method, corridors are found among patches of a selected habitat category; habitat patches are the landscape unit of consideration and all patches are treated equally. The Tool uses "virtual" walkers to simulate movements of terrestrial animals, after Gustafson and Gardner (1996). Walkers can be thought of as software agents. They are imbued with the habitat preferences of the target species so that at each step, the walker selects its direction of movement based on habitat preferences supplied for each category by the user. Only walkers that successfully reach another habitat patch are counted in the final outcome (Figure 15). Walkers that run out of energy or die along the way are discarded.

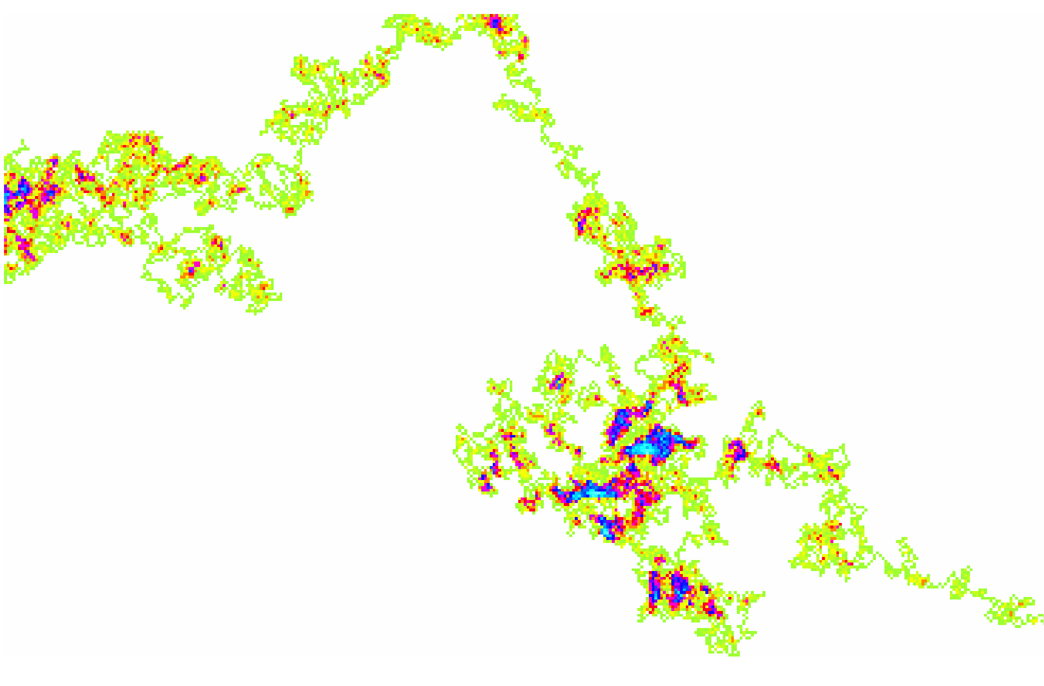

Figure 15. Example path of a single successful walker.

The “footprints” of all successfully dispersing walkers are summed together to locate corridors on the map. One can think of them as if they were well-worn footpaths. We simulated large numbers of individual walkers in a Monte Carlo process using a parallel supercomputer to find optimized potential corridors. We obtain a constant number of successful dispersers (a “success quota”) from each patch of origin. All habitat patches have an equal chance to contribute to corridors. Each walker is started at a random location within the patch of origin and each walker starts with a fixed amount of energy that is based on the size of the map. An incorporated “hot-foot” routine encourages walkers to leave their patch of origin quickly and never return. In addition, we applied an “Anti-vibrate” to discourage backtracking and give walkers realistic directional momentum. Walkers that do return to their patch of origin die, and are not counted in corridors. Walkers that enter another different patch of habitat have successfully dispersed.

The Corridor Tool is a mix between an individual-based model and a percolation analysis. Like a percolation analysis, corridor analysis is timeless or instantaneous. An ultimate potential connectivity is the result. Potential connectivity may not be realized as connectivity because there may not be any animals present in some habitat patches, or even in the whole landscape.

Several assumptions have been made to generate potential corridors:

- High quality habitat is more desirable than less-preferred habitat.
- Short, direct connectors are better than longer dispersal routes.
- Animals will follow an optimum route that minimizes their exposure to low-quality habitat.
- Movement would be facilitated by such routes, whether animals use them or not.
- Resolution of habitat map may affect the delineation of potential corridors.
- Maps must be large enough to minimize edge effects, but fine enough to reflect the scale at which the animals are making movement choices.

Although, in most cases, these assumptions seem reasonable, one will need to determine for each species to which these are applied, whether the assumptions do reflect a reality for that species.

Three types of output products are produced:

1. A map of the most heavily-traveled movement pathways between patches of each analyzed map category.
2. A square transfer matrix quantifying “flow” of animals successfully dispersing from each habitat patch to every other habitat patch of that type in the landscape. The transfer matrix is square, since the rate of animal movement is likely to be asymmetrical between any two habitat patches.

3. A set of importance values for every patch in the map that quantifies the contribution of that habitat to successful animal movement across the map. This product helps to prioritize remediation, restoration, and management triage actions.

Exchange of individuals among patches is used to calculate a quantitative importance value for each patch. Patch importance is given in the form of both a dispersal matrix and a color-coded patch map.

To carry out the large number of required calculations, we have parallelized the master/slave algorithm by habitat patch. The master node assigns each habitat patch in the map to a particular node, then the node keeps sending walkers from the assigned habitat patch until the "success quota" of successfully dispersing walkers is reached. There is a potential problem at this step as a node may be assigned a patch that is surrounded by a barrier, or is completely cut off and disconnected from the other patches. To prevent that node from endlessly sending walkers, it aborts that patch after sending a certain number of walkers without attaining the success quota. A patch that has reached the "abort quota" has less than a specified connectance. The abort quota is like the detection limit for an analytical device, except that it is under user's control.

Before they are summed, footprints of successfully dispersing walkers are weighted inversely by the square of the energy expended during their traversals. Thus, the most efficient traversal paths contribute more strongly to defining the most-probable corridors. Corridors leading from each patch can be examined individually, if desired. The corridor intensity from each patch is normalized before summing corridors from all patches together, so that all habitat patches contribute equally to the final map of landscape corridors.

Source and sink importance are independent of each other, i.e., they are intransitive. It is assumed that within-patch reproduction is equal across all patches regardless of habitat quality because in this study, there is no evaluation of individual patch quality. It is feasible to assign a relative rating to each patch, but the Corridor Model does not currently deal with this issue. Source importance is calculated as the ratio of successful dispersers originating in the patch to the total number of walkers (whether successful or not) sent from the patch. Successful walkers originating from aborted patches are counted toward source importance even though the success quota for that patch may not have been met.

In the Corridor Tool, sink importance for a patch is calculated as the ratio of successful dispersers ending up in the patch (having started from some other patch) to

the number of all successful dispersers originating from all habitat patches. Successful dispersers from aborted patches make no contribution to sink importance.

Results of the Tool for RCW

Knowing these rules of the Corridor Tool, we ran the RCW inputs and generated the results. These were sent back to CERL and integrated into the original GIS application. The following images and captions provide a tour of the results taken from the region near Fort Benning described in the previous chapter.

Evaluation of Initial Results

Sources (Figure 16) are roughly evenly distributed throughout the region; a result of the selection of the patches is based on NLCD type and minimum size. All centrally located habitat patches are roughly equal in importance as Sources of successful dispersers. Habitat patches on the periphery of the map are less important as sources, but this still depends on configuration of intervening matrix.

Figure 17 shows the importance of habitat patches as receptors or Sinks of successful dispersers. The rating for sinks is determined by a combination patch size and longest dimension. It actually depends on configuration of intervening matrix. Although the sources were basically of equal importance, Figure 17 shows that the northern sink on Fort Benning is more important than the southern Sink shown. Figure 18 shows the source-to-sink ratio. This map indicates whether populations in habitat patches are likely to be growing or shrinking due to patch placement and matrix configuration alone irrespective of within-patch reproduction. Here we see that as we trend to the south, the importance of patches as sinks increase. Conversely, the more northern patches have greater importance as sources.

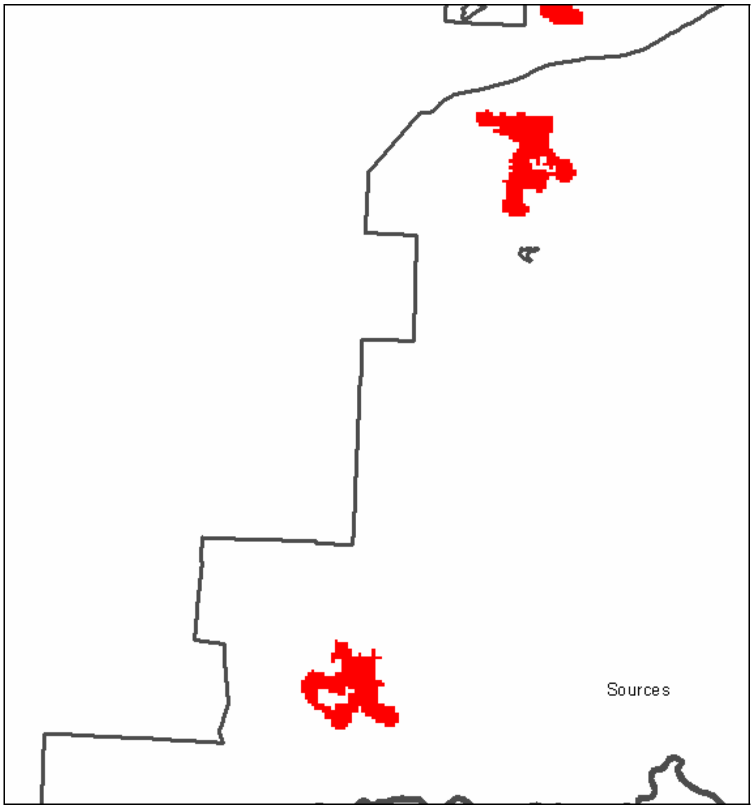

Figure 16. Source patch importance. Redder is more importance as a source.

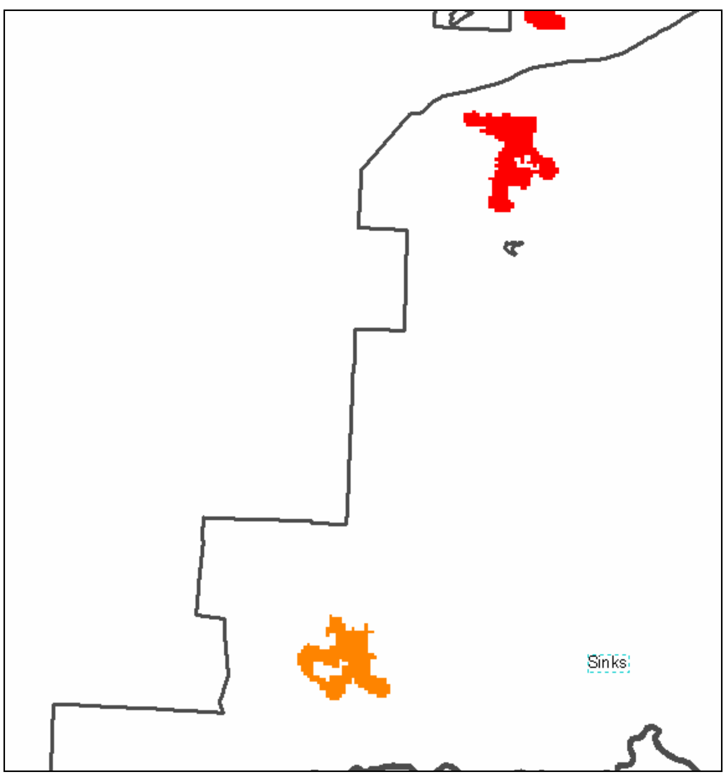

Figure 17. Importance of habitat patches as receptors or sinks of successful dispersers. The more important they are as a sink, the redder the patch color is.

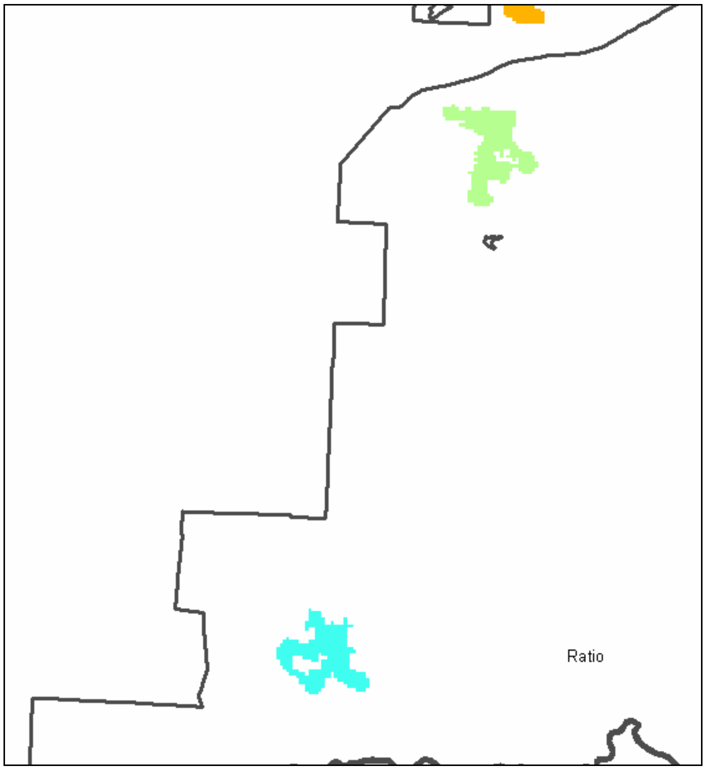

Figure 18. Source-to-sink ratio indicates whether populations in habitat patches are likely to be growing or shrinking due to patch placement and matrix configuration alone irrespective of within-patch reproduction. On a scale from blue to red, the bluer a patch is, the greater its importance as a source. Conversely, the redder the patch is, the greater its importance as a sink.

In Figure 19, we present an Area-Weighted Sink Importance of RCW Patches. This is basically a version of Figure 17 that has been normalized by the size of the patch such that, other concerns being equal, larger patches are decreased in importance since their per-unit-area importance value is diluted out over a larger area. This means that conservation and mitigation efforts are best spent on particular small patches that are vitally located. Redder shades in this image show higher importance.

Figure 20 (increasing corridor intensity) shows that there is a strong linkage between the on-installation patches along the installation boundary. However, what is extremely important from this result is that there exists a very critical linkage between the top on-installation patch and that one just off the installation. U.S. Highway 80 divides this critical linkage. This map clearly indicates the importance of the patch of installation land for RCW, as well as the potential hazard from U.S. 80 of establishing such a linkage.

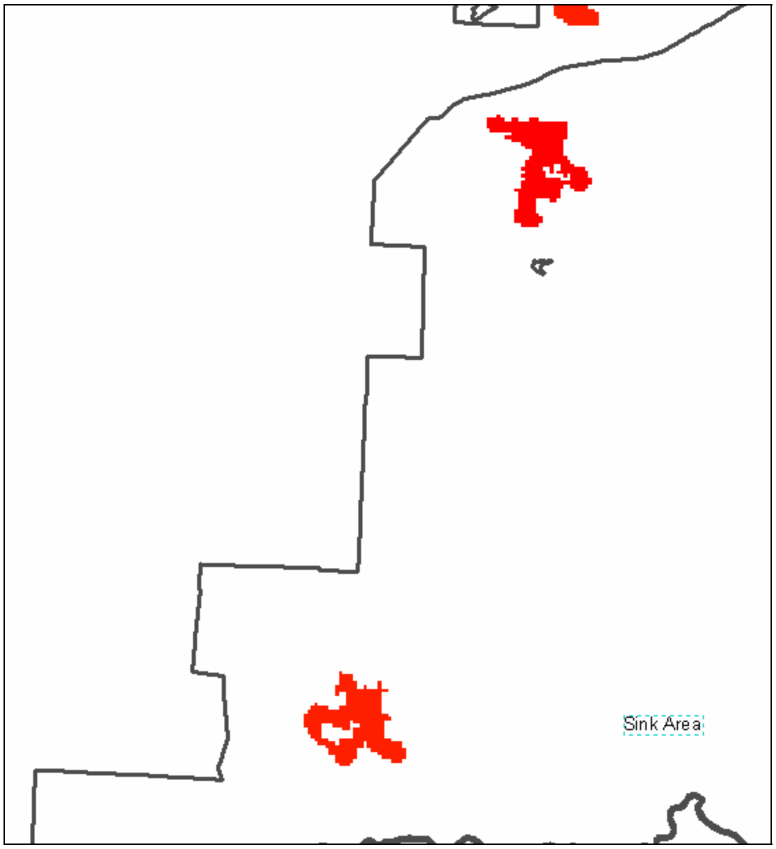

Figure 19. Area-weighted sink importance of RCW patches. In this image, redder shows higher importance.

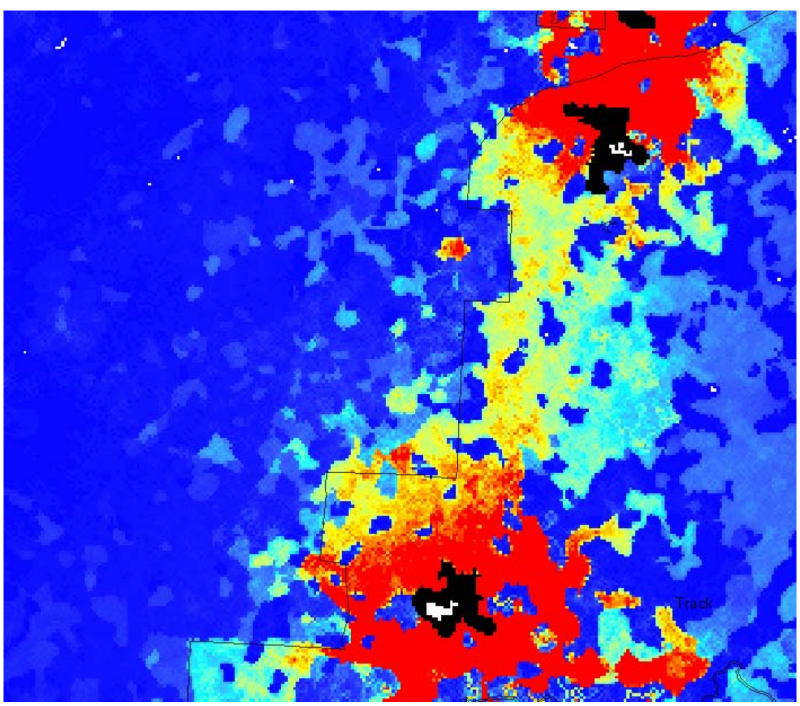

Figure 20. Increasing corridor intensity (number of footprints of successfully dispersing walkers) shown by hotter colors. Source/sink patches in black.

Figure 21 shows the same data at the regional scale. From this image, it is clear that there exist large areas (bluer area) that RCW avoid. Conversely, many areas of red and yellow show interconnection patches. Fort Benning staff have mentioned that the closest other RCW breeding colonies are about 70 kilometers to the Northeast of the installation. The top right portion of Figure 21 would include this region. Simple inspection shows that it would be difficult for RCW to follow any good linkage between these two areas. This tells land managers that expenditure of resources to connect these two populations is unlikely to result in positive results. Thus the value of this tool is to direct resources toward other areas where the likelihood is greater. In addition, by this technique, the relative degree of resources expenditures can be objectively established. This clearly demonstrates how government moneys can be put to wiser uses.

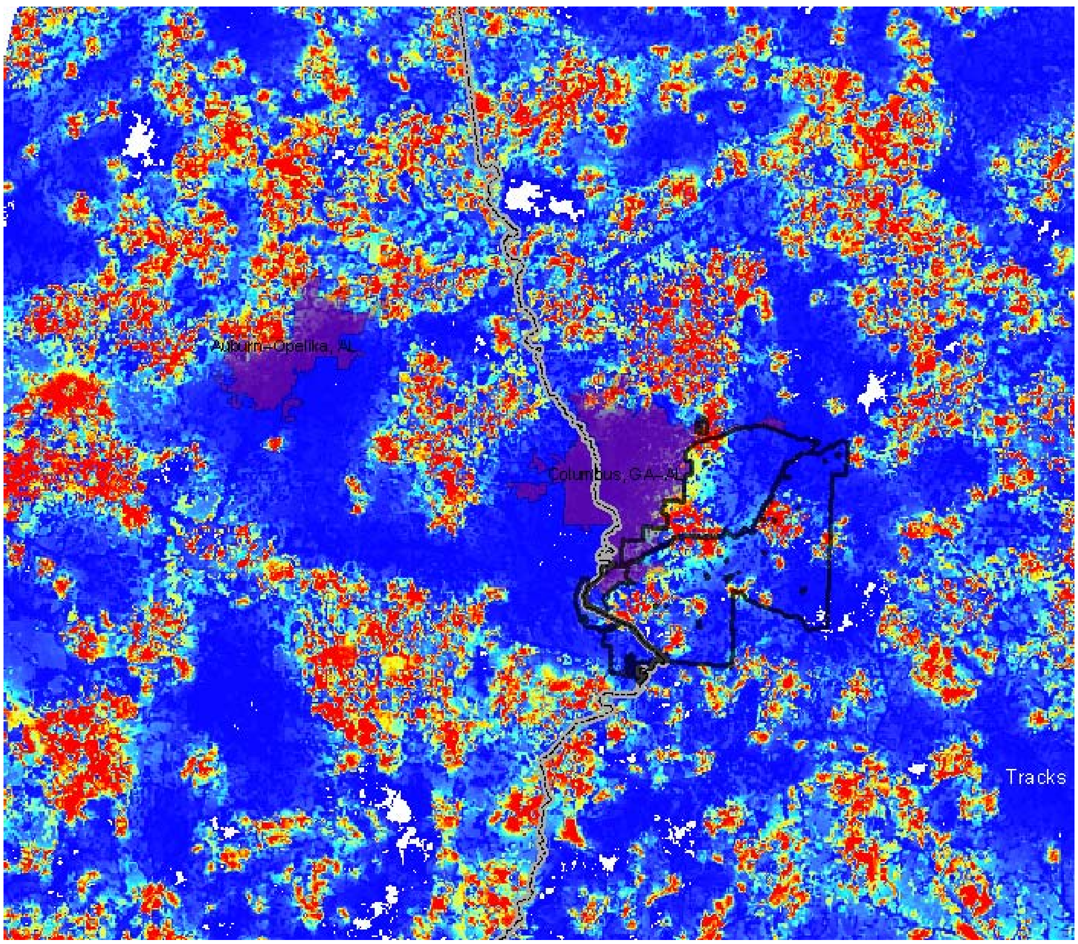

Figure 21. Tracks at the regional scale. Redder is more highly used.

Follow on Discussion

Land managers can change source/sink strengths by altering the matrix through which dispersers must pass. These changes can have significant influence even without changing the number, area, or spatial arrangement of habitat patches. Source and sink strengths are comparable across maps, since they are "unitless" ratios. This means that requesting greater numbers of successful walkers produces more precise predictions. Weighted visualizations show distinct corridors, even through realistic landscapes. Corridors through realistic landscapes are difficult to imagine before they are predicted. Dispersal corridors for invasive or weedy species are important so that they can be disrupted while dispersal corridors for threatened or endangered species are important so that they can be enhanced. These considerations should be useful in the design of biotic preserves or parks consisting of several habitat remnants.

Landscape maps may require intelligent pre-processing before they are used in a corridor analysis. Intelligent pre-processing includes coding multiple habitat categories, de-speckling, dropping out habitat patches less than a minimum usable size, and re-coding core habitat.

Least-cost path analysis between two patches with a GIS shows the single currently cheapest pathway based on preference alone, but won't show a corridor that could be made better than the current best by implementing a change in the intervening landscape matrix. A simple diffusion equation could probably predict corridors with preferences alone, but not with differential energy gains and costs, and habitat-dependent mortality. In this work, walkers were used *collectively* as a spatial optimization process to delineate optimum movement pathways. We expect animals to use these optimum pathways, because they are well adapted to their environment.

Individual walkers are *not* strictly analogous to individuals of the target species. Individual animals are much more sophisticated than walkers. Here, large numbers of walkers are used as a spatial optimization process. This optimization process is used to predict the optimum pathways that we expect individual animals to use most often. (We believe this expectation is reasonable because animals are so well adapted to their home environment.) An obverse related issue is, "Are the animals apt to be as efficient in dispersing as are the thousands of walkers in the Corridor Tool?"

Walkers that can see only the habitat types immediately adjacent to their current location can still represent animals that vary widely in the extent of their sensory range. Walkers' single-step look-ahead does not affect the optimization of potential corridors found by the algorithm because the same optimum potential corridors

would be found even if we gave walkers a greater look-ahead ability. Although shortsighted, a few walkers will make rare sub-optimal choices and will cut through bottlenecks to discover optimized pathways beyond. Conversely, walkers that enter attractive, but dead-end, patches will not successfully disperse; potential corridors that result will effectively show this avoidance of dead-end routes, just as though walkers had greater sensory range. Because animals have a memory, they will use optimum routes, once discovered or learned. However individual walkers do not need memory, since optimized routes are found by the collective action of large numbers of (only) successful walkers.

Summary of Results

The results application of the Corridor Tool to the RCW data indicate that:

- The inputs can be configured and the application can be successfully run based on known characteristics of a TES species.
- The results appear reasonable in terms of the character of the TES under review.
- The Corridor Tool has the potential to be of significant use to land managers in general and specifically to Military land managers dealing with TES concerns, particularly in off-installation areas where little about potential habitat and habitat fragmentation are known. The NLCD provide a basis over a region. However, it appears that the NLCD is severely limited due to the fact that there are so few categories, especially categories that relate specifically to the critical issues for the RCW. When we evaluated the patches input map, there were many, regularly dispersed patches of potential RCW habitat. Even before running the Corridor Tool, researchers believed that these regular patches were going to be well connected with a regular netlike network of corridors. This input map does not suggest that it would belong to a TES. Instead, it gives the impression of abundance and regular dispersion of habitat patches. It looks like this species could easily (even abundantly) live on this landscape. In other words, it appears that this evaluation *overestimates* the good habitat for RCW in our input map. It is true that probably not *all* evergreen patches truly represent RCW habitat. In fact, only the oldest evergreen patches that still have tall living trees are actually habitat. Therefore we expect the corridors are accordingly overestimated. Unfortunately, at the landscape scale there is no way to accurately distinguish evergreen patches that are truly appropriate for RCW use.
- Therefore, the patches of sources must be more explicitly developed. Refining these patches using the original imagery (Figure 22) would be a worthwhile next step.

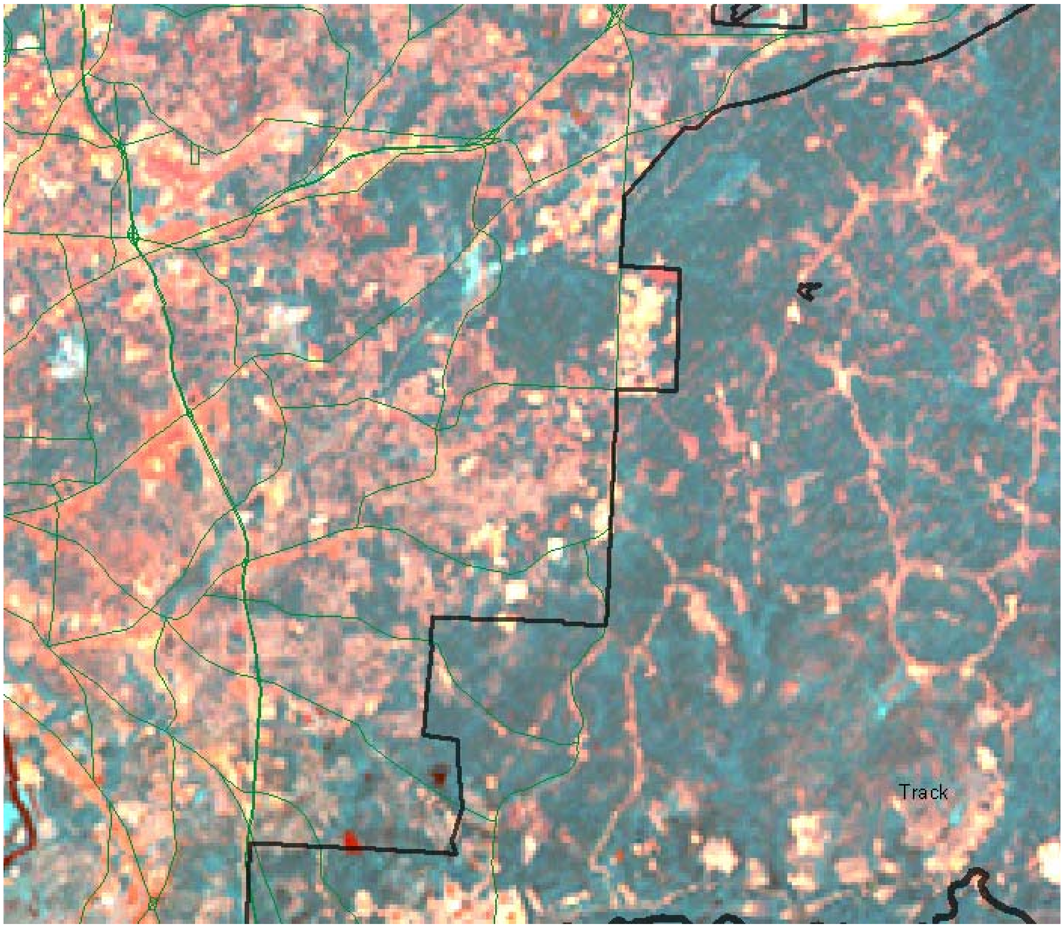

Figure 22. A portion of the NALC 1980 image for the zoomed-in area.

5 Conclusions and Recommendations

Conclusions

This study tasking has generated (and demonstrated the feasibility of generating) the needed input for the ORNL Corridor Tool for a specific TES, RCW, in this example, by using a combination of state of the art GIS tools and manipulations at a landscape scale. Inputs for the RCW model can be objectively derived by correlating known RCW locations ("Ground Truth") with landscape scale data sources (e.g., the NLCD land uses). This study concludes that:

- The conceptualization of the algorithms intrinsic to the Corridor Tool provide a solid basis for modeling the behavior of animals as they journey between home patches within their environment.
- This behavior can be modeled at the landscape scale in the real world situation.
- This modeling can be applied to TES as with any other animals.
- The inputs can be configured and the application can be successfully run based on known characteristics of a TES species.
- The process appears to achieve reasonable results in terms of the character of the TES under review.
- The Corridor Tool has the potential to be of significant use to land managers in general and specifically to Military land managers dealing with TES concerns particularly in off-installation areas where little about potential habitat and habitat fragmentation are known.
- As a data source, the NLCD is severely limited due to the fact that there are so few categories, especially categories that relate to the specific critical issues for the RCW.
- The results of this effort can provide military land managers with important information about critical land corridors off installation that are critical to the off-installation viability of TES.

Recommendations

Because the Corridor Tool offers so many advantages over classical least-cost analyses, this study recommends that follow-on work:

- Cover additional spatial area (e.g., over the entire RCW habitat) using the NLCD.
- Include expanded temporal coverage (to see how the corridors have changed over time),
  - in the past (e.g., from the Sandhills data set)
  - into the future in cooperation with the development of spatially explicit land use change prediction models (e.g., the Land Evolution Analysis Model – LEAM).
- Test the Corridor Tool on additional TES species (e.g., the Gopher Tortoise) to see if the habitat delineation can be improved.

Since the NLCD provides a basis over a region, but is severely limited due to the fact that there are so few categories, especially categories that relate to the specific critical issues for the RCW, it is recommended that the patches for the sources be more explicitly developed using the original imagery (Figure 22, p 31).

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U.S. Fish and Wildlife Service (USFWS), *Recovery Plan for the Red-cockaded Woodpecker (<u>Picoides borealis</u>),* 2d rev. (USFWS, Atlanta, Georgia, 2003).

Acronyms and Abbreviations

Term	Spellout
ASCII	American Standard Code for Information Interchange
CERL	Construction Engineering Research Laboratory, Part of ERDC
CNN	Ecological Processes Branch within CERL
CPU	Central Processing Unit
ERDC	Engineering Research and Development Center
ESRI	Corporation that supplies ArcView GIS software
FWS	(U.S.) Fish and Wildlife Service
GIS	Geographical Information System
NLCD	National Land Cover Data
ORNL	Oak Ridge National Laboratory
RCW	Red-cockaded Woodpecker
TES	Threatened or Endangered Species
URL	Universal Resource Language
USFWS	U.S. Fish and Wildlife Service

Appendix A: Literature Review Items Used To Generate the Corridor Tool Inputs

RCW Corridor/Habitat Considerations

From *NatureServe*:

http://www.natureserve.org/explorer/servlet/NatureServe?menuselect=none&sourceTemplate=tabular_report.wmt&loadTemplate=species_RptSumm.wmt&selectedReport=RptSumm.wmt&summaryView=tabular_report.wmt&elKey=ABNYF07060&paging=home&save=true&startIndex=1&nextStartIndex=1&reset=false&offPageSelectedElKey=ABNYF07060&offPageSelectedElType=species&offPageYesNo=true&post_processes=&radiobutton=radiobutton&selectedIndexes=ABNYF07060&menuselectfooter=none

A comprehensive 3-year study by Hooper et al. (1982) reported home ranges from 34-225 ha (mean of total ranges 86.9 ha, with a mean of year-round ranges of 70.3 ha). In other studies, home range estimates varied from 15-220 ha and averaged around 67 ha (Baker 1977, Crosby 1971, Skorupa and McFarlane 1976, Nesbitt et al. 1978, Sherrill and Case 1980, Nesbitt et al. 1983b, Wood 1983a), although extremely large territories of about 400 ha may exist (Hooper et al. 1980).

Relation to ORNL measures

The home range radius was from 300m to 750m (at 60 meter cells, 5 to 12.5 cells radius), with a 415 meters average radius (7-60 meter cells). Put a buffer of 7 60meter cells beyond best habitat for foraging.

Home range estimates may include "extra-territorial" areas that are used by other neighboring conspecifics as well as by floaters in the population (Walters 1989). These are not strongly defended and are estimated to average about 8.4 ha (Hooper et al. 1982), but may be as large as 30 ha (Hooper et al. 1982, Repasky 1984, Blue 1985, Porter and Labisky 1986, DeLotelle et al. 1987). Repasky (1984) suggested that extra-territorial range is underestimated because sampling is usually not extensive in winter and late summer when birds use larger areas. However, in the few studies in which home range size estimates were subdivided into territorial and extra-territorial areas, similar mean territory sizes of 70 ha were obtained (Hooper et al. 1982, Repasky 1984, Blue 1985).

Relation to ORNL measures: Same as above.

In North Carolina, fledgling females dispersed an average of 4.8 km, and a maximum of 31.5 km. Breeding males dispersed an average of 2.1 km, and a maximum 15 km. Fledgling males dispersed an average of 5.1 km, and a maximum 21.1 km. Helper males dispersed an average of 1.8 km, and a maximum 17.1 km. Solitary males dispersed an average of 2.3 km, and a maximum 8.5 km (Walters 1989).

Relation to ORNL measures: Dispersal goes down from known patches of RCW at distance intervals of about 4km "half-life" Buffers. Raise mortality to transit cells not habitat in 4km buffers.

The relatively short dispersal distance implies that rates of inbreeding may be high even though close inbreeding is avoided (Walters 1990). That is, matings between second cousins may be common while parent-offspring matings are avoided. This may have led to the high similarities of DNA profiles reported by Haig et al. (1993b). However, Walters (1988) described a long-distance dispersal event for one female, which moved 90 km and seemed to follow a highway corridor that contained appropriate habitat conditions. The bird also traversed unfavorable habitats.

Relation to ORNL measures: Highways within a habitat are good dispersal corridors.

Optimal habitat is characterized as a broad savanna with a scattered overstory of large pines and a dense groundcover containing a diversity of grass, forb, and shrub species (Hooper et al. 1980, AOU 1991). Midstory vegetation is sparse or absent (Hooper et al. 1980, Locke et al. 1983, Hooper et al. 1991, Loeb et al. 1993).

Relation to ORNL measures: Standard knowledge.

Roosting and nesting cavities have been found in longleaf, loblolly (*Pinus taeda*), shortleaf (*Pinus echinata*), slash (*Pinus ellioti*), pond pine (*Pinus rigida*), and even bald cypress (*Taxodium disthicus*) (Dennis 1971). Some evidence suggests longleaf pine is preferred even when mature stands of other pine species are available (Hopkins and Lynn 1971, Lay and Sweptson 1973, Baker 1981, Lennartz et al. 1983, Hovis and Labisky 1985, Ligon et al. 1986). The historic distribution of longleaf coincides with the region where Audubon (1839) reported the greatest abundance of Red-cockaded Woodpeckers. In addition, relict stands of old-growth longleaf today have some of the highest densities of this species (Engstrom 1982, Carter et al. 1983).

Relation to ORNL measures: Longleaf most desirable species

Longleaf most desirable species appear to use a wide range of pine and hardwood habitats (Hooper et al. 1980, U.S. Fish and Wildlife Service 1985),

Relation to ORNL measures: Pine/evergreen is OK.

When clearing reduces the foraging habitat to less than 40 ha, persisting groups may have difficulty raising young. Conner and Rudolph (1991b) found that the removal of forest cover within 800 m of cavity clusters was associated with cluster inactivation.

Relation to ORNL measures: Patches of less than 40 ha (400,000 sq meters or 111 cells of 60 meter size) is too small for viable habitat.

Seagle et al. (1992) compared characteristics of forest compartments with active colonies and those having no colonies. Active clusters were associated with: (1) an increased acreage of mature longleaf pine; (2) an increased acreage of all pine species; (3) a decreased percentage of acres of longleaf, loblolly, and slash pines in stands less than 20 acres in size; (4) a decreased percentage of acres of mature loblolly pine; and (5) a decreased acreage of loblolly pine between ages 20 and 39 years.

Relation to ORNL measures: Larger habitat patches are better, previous 40 ha patch may be too small, maybe 175 cells more appropriate.

Foraging occurs in a diversity of forested habitat types that includes pines of various ages as well as some hardwood-dominated habitats. Despite this seemingly broad use of different habitat types, most foraging appears to take place on older pine trees or in open pine habitats (Baker and Thompson 1971, Hooper et al. 1980, Hooper and Lennartz 1981, Delotelle 1983).

Relation to ORNL measures: Foraging best in pines (evergreens) OK in hardwoods (decedious).

Delotelle et al. (1983) found that live pine stems greater than 23 cm dbh represented only 19 percent of available foraging substrate in central Florida but received 65 percent of the use, and also found that longleaf pine was used as the foraging substrate 90 percent of the time.

Relation to ORNL measures: Ditto

Landscape features, such as fragmentation of foraging habitat, total area of foraging habitat, percentage of pinewood or hardwood cover, contiguity of the canopy and forest cover, and habitat patch size and shape may affect the habitat quality (Hooper et al. 1980, SNN 1990, Conner and Rudolph 1991b). The importance of such variables is not well known (Walters 1991), but a growing body of research focuses on this issue, particularly on some public lands where timber harvest patterns may create unfavorable landscapes (Conner and Rudolph 1991b). A potential problem in such research is the key role that cavity trees play in determining whether an area is ever actually used by Red- cockaded Woodpeckers (Walters 1991). Areas that have suitable habitat characteristics, yet lack suitable cavity trees, will not likely be occupied by Red-cockaded Woodpeckers (Walters 1991), and thus some comparisons will be misleading.

Relation to ORNL measures: Landscape metrics not yet known.

Conner and Rudolph (1991b) found that foraging habitat could be fragmented and isolated as a result of forest-harvest patterns, and that larger groups of woodpeckers had consistently fewer clear cuts near cavity sites. Fragmentation did not appear to have an effect on dispersal (e.g., the ability of dispersing females to find unmated males), but it did apparently affect the quality of foraging habitat. Conner and Rudolph (1991b) warned that it may be possible to have a sufficient quantity of foraging habitat within 800 m of an active cluster, but still have insufficient arrangement of foraging habitat. Fragmentation influenced a group's access to foraging habitat by forcing birds to go through territories of adjacent groups. This increases the probability of cluster inactivation.

Relation to ORNL measures: Good habitat near no habitat is not good for foraging.

Appendix B: Corridor Tool Matrix Input Table

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree Of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
1	2	4	60 m–4 km	Avoid	0	No compatibility—Straight from Relative Degree of Preference	0.15	Birds can transit, but further from more suitable areas so less likely, possibly find a bit	0.94	Birds die and transiting increases that slightly
2	2	3	60 m–4 km	No Matter	0.28	This is normal home range	0.25	Poor area to gather food and far away from good habitat	0.96	Transiting Birds are further away from best habitat
3	2	2	60 m–4 km	High	0.8	Within normal home range	0.75	Nearly Good	0.97	Transiting Birds can be a long way from best habitat
4	2	1	60 m–4 km	Highest	0.99	This is normal home range	0.95	Nearly Best, similar to “At Home” situation	0.98	Transiting Birds are further away from best habitat
5	1	3	Best RCW Habitat Patch	No Matter	0.29	Moderate compatibility—Straight from Relative Degree of Pre	0.3	Poor area to gather food	0.97	Nearly as safe as being at home.
6	1	2	Best RCW Habitat Patch	High	0.81	High compatibility—Straight from Relative Degree of Preference	0.81	Good	0.98	Nearly as safe as being near home.
7	1	1	Best RCW Habitat Patch	Highest	1	Straight from Relative Degree of Preference—area Not large enough for viable colony	1	Best, similar to “At Home” situation	0.99	Nearly as safe as being near home.

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree Of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
8	1	4	Best RCW Habitat Patch	Avoid	0	No compatibility—Straight from Relative Degree of Preference	0.2	Birds can transit, possibly find a bit	0.95	Nearly as safe as being at home but now may be a long distance.
9	1	5	Best RCW Habitat Patch	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.3	Poor area to gather food	0.97	Away from normal cover—vulnerable, even though not very likely
10	2	5	60 m–4 km	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.25	Poor area to gather food and far away from good habitat	0.96	Away from normal cover—vulnerable, even though not very likely
11	2	6	60 m–4 km	Water	0.02	Water is not a RCW habitat	0.05	No RCW Food in water areas, more distant from suitable areas so 1/2 previous	0.96	Away from normal cover—vulnerable, even though not very likely
12	1	6	Best RCW Habitat Patch	Water	0.02	Water is not a RCW habitat	0.1	No RCW Food in water areas, however water availabilty is positive, prevents zero rating.	0.97	May be a long way from normal cover
13	3	3	4 km–8 km	No Matter	0.23	Slightly beyond home range	0.25	Poor area to gather food and far away from good habitat	0.96	Away from normal cover in a place normally to avoid—vulnerable, even though not very likely

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree Of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
14	3	4	4 km–8 km	Avoid	0	No compatibility—Straight from Relative Degree of Preferenc	0.15	Birds can transit, but further from more suitable areas so less likely, possibly find a bit	0.94	Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
15	3	2	4 km–8 km	High	0.75	Slightly beyond home range	0.75	Nearly Good	0.97	Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
16	3	5	4 km–8 km	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.25	Poor area to gather food and far away from good habitat	0.96	Can be really far Away from normal cover in a place normally to avoid—vulnerable, even though not very likely
17	3	1	4 km–8 km	Highest	0.95	Slightly beyond home range	0.95	Nearly Best, similar to “At Home” situation	0.98	Away from normal cover—vulnerable, even though not very likely
18	3	6	4 km–8 km	Water	0.02	Water is not a RCW habitat	0.025	No RCW Food in water areas, more distant from suitable areas so 1/2 previous	0.96	Away from normal cover—vulnerable, even though not very likely
19	4	2	Greater Than 8 km	High	0.65	Beyond normal range	0.75	Nearly Good	0.96	Away from normal cover—vulnerable, even though not very likely

Lu Category	Mig Buf Value	RCW Preferences	Migration Dist	Ranking	Relative Degree Of Habitat Preference 1=Best	Reason For Relative Degree Of Habitat Preference	RCW Energy Cost To Transit Foraging (1-0)	Reason For RCW Energy Cost To Transit Foraging	Mortality For Transit (1-0) 1=No Mortality	Reason For Mortality For Transit
20	4	4	Greater Than 8 km	Avoid	0	No compatibility—Straight from Relative Degree of Preference	0.15	Birds can transit, but further from more suitable areas so less likely, possibly find a bit	0.93	May be a long way from normal cover
21	4	3	Greater Than 8 km	No Matter	0.18	Beyond normal range	0.25	Poor area to gather food and far away from good habitat	0.95	Similar to Moderate
22	4	1	Greater Than 8 km	Highest	0.85	Beyond normal range	0.9	Nearly Best, similar to “At Home” situation	0.97	Similar to Moderate
23	4	5	Greater Than 8 km	Urban-Avoid	0.05	Urban areas are to be avoided if possible	0.25	Poor area to gather food and far away from good habitat	0.95	Similar to Moderate
24	4	6	Greater Than 8 km	Water	0.02	Water is not a RCW habitat	0.012	No RCW Food in water areas, more distant from suitable areas so 1/2 previous	0.93	Greater than 8 km may be a long way to fly, increased danger.
25	1	1	Best RCW Habitat Patch	Highest	1	Straight from Relative Degree of Preference, area large enough for viable colony	1	Best, similar to “At Home” situation	0.99	Nearly as safe as being near home.

Appendix C: Land Use Definitions

Table C3. NLCD land cover classification system land cover class definitions used.

Term	Definition
Water	All areas of open water or permanent ice/snow cover.
Open Water	Areas of open water, generally with less than 25 percent or greater cover of water (per pixel).
Perennial Ice/Snow	All areas characterized by year-long cover of ice and/or snow.
Developed	Areas characterized by high percentage (approximately 30% or greater) of constructed materials (e.g., asphalt, concrete, buildings, etc).
Developed (Low Intensity Residential)	Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
Developed (High Intensity Residential)	Includes heavily built up urban centers where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80-100 percent of the cover.
Commercial / Industrial / Transportation	Includes infrastructure (e.g., roads, railroads, etc.) and all highways and all developed areas not classified as High Intensity Residential.
Barren	Areas characterized by bare rock, gravel, sad, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.
Bare Rock / Sand / Clay	Perennially barren areas of bedrock, desert, pavement, scarps, talus, slides, volcanic material, glacial debris, and other accumulations of earthen material.
Quarries / Strip Mines / Gravel Pits	Areas of extractive mining activities with significant surface expression.
Transitional	Areas of sparse vegetative cover (less than 25 percent that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g., fire, flood, etc.)
Forested Upland	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); Tree canopy accounts for 25-100 percent of the cover.
Deciduous Forest	Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	Areas characterized by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest	Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.
Shrubland	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall with individuals or clumps not touching to interlocking. Both evergreen and diciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

Term	**Definition**
Shrubland	Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g., herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.
Non-natural Woody	Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.
Orchards / Vineyards / Other	Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.
Herbaceous Upland	Upland areas characterized by natural or semi- natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.
Grasslands / Herbaceous	Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often used for grazing.
Planted/Cultivated	Areas characterized by herbaceous vegetation That has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.
Pasture/Hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
Row Crops	Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.
Small Grains	Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
Fallow	Areas used for the production of crops that are temporarily barren or with sparse vegetative cover as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
Urban / Recreational Grasses-	Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.
Wetlands	Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.
Woody Wetlands	Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

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14. ABSTRACT

Researchers at the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL, determined that a "Corridor Tool" developed by the Oak Ridge National Laboratory (ORNL) could serve to further focus ongoing "habitat" research on habitat fragmentation at the landscape scale. This work tested the ORNL Corridor Tool on data related to Red-cockaded Woodpecker habitat fragmentation in the southeastern United States using widely available data to run the Corridor Tool, and to develop a general corridor analysis.

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